NASA-CR-198843

56879
P. 8

Final report for NASA Grant NAG-1-168
Structural Optimization of Composite Structures

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June 1995

(NASA-CR-198843) STRUCTURAL OPTIMIZATION OF COMPOSITE STRUCTURES Final Report, 1 Sep. 1981 - 15 Jan. 1995 (Florida Univ.) 8 p

N95-71526

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Z9/24 0056879

General

This is the final report for NASA grant NAG1-168 covering the period of 9/1/81 to 1/15/95.

Personnel

This grant supported in full the following graduate students:

1. Zafer Gürdal, Ph.D 1984, presently Associate Professor of Engineering Science and Mechanics at Virginia Tech.
2. Rajiv Thareja, Ph.D 1986, presently with Lockheed Engineering and Science Corp. Hampton Virginia.
3. Paras Mehta, M.S., 1987, presently at Ford Motor Company, Dearborn, Michigan.
4. Yung Shin, Ph.D, 1988, presently an Associate Professor at Hua University in Korea.
5. Uma Madapur, M.S., 1988, presently with Abacus, Providence, Rhode Island.
6. S. Sankaranarayanan, Ph.D., 1992, presently working as a contractor for Ford Motor Company in Dearborn, Michigan.
7. Somanath Nagendra, Ph.D 1993, presently at General Electric Corporate Research Center, Schenectady, New York.
8. Pradeep Sensharma, Ph.D 1993, presently at Designers&Planners, Arlington, Virginia.
9. Rodolphe Le Riche, Ph.D 1994, presently serving in the French Army.

In addition the grant provided partial support to the following students.

1. Yehuda Katz, visiting student from the Technion in Israel.
2. Delphine Jestin, visiting student from the Technological University of Compiegne, France.
3. Willem Roux, visiting student from the University of Pretoria, South Africa.
4. Marco Lombardi, MS 1994, now completing his Ph.D at the University of Pavia, Italy.
5. Satish Haryadi, Ph.D student at Virginia Tech.
6. Vladimir Balananov, Ph.D student at Virginia Tech.

The grant also supported Post Doctoral Associates:

1. Peter Harrison, still at Virginia Tech.
2. Pradeep Sensharma, presently at Designers and Planners, Arlington Virginia.

Summary of Technical Accomplishements

Optimization Methodology

Composite Structures offer the designer a great deal of flexibility to tailor the design to the particular requirements of the structural problem. However, unlike metal structures they can have very little resistance to conditions which has not been designed for, such as damage. Work under the grant demonstrated this vulnerability (Ref. 1), but showed that when damage is taken into consideration early in the design process, the design can be made damage tolerant with little mass penalty. Work under the grant also established that composite panels can have a large number of different near optimal designs (Ref. 2). Design for damage tolerance requires consideration of a large number of possible damaged configurations, and methods that permit efficient optimization against damage were developed (Ref. 3,4).

Composite laminates are traditionally designed by using continuous optimization techniques. Final designs are then rounded to an integer number of plies. This often lead to non-optimal designs and fails to find the multiple near optimal designs that would be of interest to the designer. The first difficulty can be surmounted by using integer programming techniques. The work under the grant developed several techniques for using branch-and-bound search for designing laminate stacking sequences (Refs. 5,6). However, since branch and bound techniques do not provide multiple designs, the emphasis shifted to the use of random search techniques. Simulated annealing was checked and found wanting (Ref. 6), but genetic algorithms provided multiple designs at somewhat high computational cost. An intense effort ensued (Refs. 8–17) to develop a genetic algorithm which can efficiently obtain designs of composite laminates. The resulting algorithm has special features such as a permutation operator tailored to the particularities of composite laminate. In recently completed work (Ref. 18), the genetic algorithm found a large number of designs which were lighter than previously obtained (Ref. 19) continuous optimum by as much as eight percent.

A second optimization method developed under the grant was simultaneous analysis and design (SAND). SAND casts the analysis and optimization problems as a single optimization problem where both displacement and design variables are obtained simultaneously. This method was first suggested in the 1960s and abandoned because of excessive computational cost. Under the grant it was shown that with modern algorithms, the SAND approach is competitive for general problems (Refs. 20–25). It is particularly attractive for topology optimization problems where the number of displacement design variables is not much larger than the number of structural design variable (Refs. 26, 27). The approach was used to identify the internal structure needed for the high speed civil transport (Ref. 28).

A third optimization approach explored under the grant was the homotopy method (Refs. 2, 29–31). This approach allows us to obtain in a single execution solutions for a whole range of a single parameter. This appraoch was used to obtain composite panels designed for maximum buckling load for a range of weight budgets. This approach is particularly powerful when the set of optimal designs of a structural component needs to be explored for incorporation in a more complex structure.

Finally, work under the grant included also the development of an optimization package NEWSUMTA (Ref. 32), the exploration of the relationship between single-level and multi-level optimization (Ref. 33, 34), surveys of optimization methods (Ref. 35, 36) and optimization for improved reliability (Ref. 37).

Design of Panels with Cutouts

Composite materials can be more sensitive than metal structures to the effect of cutouts because in metal structures plastic flow permits more easily load redistribution after local failure. The work under the grant developed methods for designing panels with cutouts. This work had a substantial experimental component, and it was performed jointly with the grant monitor Dr. James H. Starnes, Jr.

Early work on the grant (Refs. 38–43) focused on the design of composite plates with slots (simulating cracks). A failure model based on microbuckling was developed and verified by tests. Sensitivity derivatives for boundary conditions typically applied in compressive tests were also developed and used in an optimization procedure.

Next the work shifted to the design of composite plates with circular holes. Work with unstiffened panel revealed that stiffening the hole area was not effective, but that removing 0-deg material from that region improved strength at the same time that it reduced weight (Ref. 44).

For the design of stiffened composite plate with a circular hole, a local-global procedure using a finite element proram, EAL, together with a panel design code, PASCO, was developed (Ref. 19). The approach permits the use of the efficient buckling analysis in PASCO together with finite element analysis of local stresses near the hole. Some of the designs were tested in the laboratory, with good agreement between experimental results and analytical models (Ref. 45).

Work was also conducted on reducing the stress concentration near the hole by variable fiber orientation (Ref. 46), and by induced strain actuation using piezoelectric actuators (Ref. 47–50). Finally, work is ongoing on the use of a combined finite element and Ritz procedure for calculating inexpensively the stress field near a hole (Ref. 51).

Miscellaneous

Work under the grant also included the study of aeroelastic optimization of a swept forward wing together with Mark Shuart and Richard Campbell of NASA Langley (Ref. 52), and the studey of postbuckling of unsymmetrically laminated composite plate (Refs. 53–54).

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